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# Detecting exchange rate contagion in Asian exchange rate markets using asymmetric DDC-GARCH and R-vine copulas.

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## Abstract

This study uses asymmetric DCC-GARCH models and copula functions for studying exchange rate contagion in a group of twelve Asia-Pacific countries. Using daily data between November 1991 and March 2017, shows that extreme market movements are mainly associated with the high degree of interdependence registered by countries in this region. The evidence of contagion is scarce. Asymmetries do not appear to be important. Specifically, currency comovements are statistically identical during times of extreme market appreciation and depreciation, indicating that phenomena such as the fear of “appreciation” do not appear to be relevant in the region’s foreign exchange markets.

*Keywords:* Exchange rate contagion; Asian financial crisis; Copula functions; DCC-GARCH models.

*JEL Classification:* C32; C51; E42.

## 1. Introduction

This paper studies exchange rate contagion in Asia-Pacific markets between 1991 and 2017 following an R-vine copula approach. As in Forbes & Rigobon (2001), contagion consists of a significant increase in cross-market linkages after the occurrence of a shock in a country’s financial market. Defining contagion this way offers two important advantages. First, it allows distinguishing between temporal and permanent mechanisms for the transmission of crises, facilitating the implementation of macro-prudential policies. Second, it provides a useful framework for empirically testing contagion in a very general setup. We use here the tail dependence criterion proposed by Cherubini, Luciano, & Vecchiato (2004), used in related studies including Czado, Schepsmeier, & Min (2012) and Loaiza-Maya, Gómez-González, & Melo-Velandia (2015a,b).

Contagion during currency crisis has been extensively studied. Much of the ample empirical literature emphasizes on its geographical component (see Lee & Kim, 1993; Forbes & Rigobon, 2001; Dungey, Fry, González-Hermosillo, & Martin, 2006; Lucey & Voronkova, 2008; Aroui, Bellalah, Hamida, & Nguyen, 2012). Currency crises tend to be regional, as they affect countries in geographical proximity Glick & Rose (1999); De Gregorio & Valdes (2001); Beirne

& Gieck (2014).

Studying developed and Asia-Pacific exchange rate markets from the 1990s on is interesting for various reasons. First, the term “contagion” in financial markets began to be used after the Asian banking and currency crises of 1997 (Claessens & Forbes, 2001). There is relative consensus in the literature that these are benchmark events for studies on interdependence and spillovers among financial markets. Hence, providing further evidence for a better understanding of contagion during those episodes is always useful. Second, the Asian-Pacific region’s importance in the global economy is growing. Estimates of the IMF indicate that, by 2030, Asia’s economy will be larger than that of the United States and the European Union combined. Countries in this region are also gaining increasing importance in international financial markets and, therefore, their potential of transmitting volatility shocks to other emerging and developed economies (R. F. Engle, Gallo, & Velucchi, 2012). Finally, currency markets in the region have undergone important reforms and transformations over the last two decades. Thus, data presents sufficient heterogeneity for identifying interdependence and contagion appropriately.

Results show that Malaysia ringgit is central in the region’s exchange rate network. On the contrary, Japan yen and New Zealand dollar are the least integrated currencies in the network. Contrasting with recent studies that have encountered evidence of contagion in Latin American and East European countries, this paper shows that little

evidence of contagion is encountered for the Asia-Pacific region. Exchange rate co-movements are mainly due to high interdependence between countries, as in Forbes & Rigobon (2001). Asymmetries are of minor importance. In fact, for most pairs of countries, a symmetric behavior is identified, suggesting that co-movements during currency appreciation and depreciation are statistically identical.

This paper is organized as follows. Section 2 is a data section. Descriptive statistics are presented. Section 3 introduces the ARIMA-GARCH best models and the DCC specification to account for asymmetric effects to obtain the standardized residuals. The Sklar's theorem is presented in Section 4 along with R-vine and tail dependence definitions which are used in Section 5 for empirical estimations. The last section concludes.

## 2. Data and descriptive statistics

This document covers a synchronized period from 7/Nov/1991 to 16/Mar/2017 for daily closing values obtained from Bloomberg L.P. Exchange rate data is gathered for the twelve Asia-Pacific economies: Australia (AUD), Hong Kong (HKD), India (INR), Indonesia (IDR), Japan (JPY), Malaysia (MYR), New Zealand (NZD), Singapore (SGD), South Korea (KRW), Thailand (THB), Taiwan (TWD) and The Philippines (PHP). Nominal exchange rates are depicted in Figure 2.

Table 1 presents descriptive statistics for exchange rate returns.<sup>1</sup> Notice that means are positive and negative indicating devaluations and appreciations over the period of study. Return distribution are skewed, presenting higher mass on right tails as well as left tails. This fact illustrates that currencies are affected by depreciations and appreciations. However, it appears to be the case that appreciations are more frequent within individual countries' exchange rates and justify the exploration of asymmetries in interdependence and contagion.

Interestingly, excess Kurtosis are positive in all cases. The distribution exhibit platykurtic distributions, having fewer extreme values. This empirical fact indicates that most countries in the Asia-Pacific region exhibit few episodes of high exchange rate volatility, possibly associated with active central bank exchange rate intervention policies. However, considerable heterogeneity is observed between countries.

Jarque-Bera test results provide evidence for rejecting the normal distribution hypothesis in all countries at conventional confidence levels. Additionally, D-values for Kolmogorov-Smirnov statistics are positive, providing further evidence that returns are not normally distributed.

These evidence together suggests the importance of exploring alternative distributions that can better represents exchange rate returns and their dependence structures.

## 3. ARIMA-GARCH

The best fit ARIMA models are calculated according to (BIC and AIC) for each currency, as shown in Table 2. The standard GARCH specification is applied:

$$\sigma_t^2 = \alpha_0 + \alpha_1 u_{t-1}^2 + \beta \sigma_{t-1}^2, \quad (2)$$

using a Student- $t$  conditional distribution as proposed by Hansen (1994):

$$g(z|\eta, \lambda) = \begin{cases} bc \left( 1 + \frac{1}{\eta-2} \left( \frac{bz+a}{1-\lambda} \right)^2 \right)^{-(\eta+1)/2} & z < -a/b, \\ bc \left( 1 + \frac{1}{\eta-2} \left( \frac{bz+a}{1-\lambda} \right)^2 \right)^{-(\eta+1)/2} & z \geq -a/b, \end{cases} \quad (3)$$

where  $2 < \eta < \infty$ , and  $-1 < \lambda < 1$ . The constants  $a$ ,  $b$ , and  $c$  are given by  $a = 4\lambda c \left( \frac{\eta-2}{\eta-1} \right)$ ,  $b^2 = 1 + 3\lambda^2 - a^2$ , and

$$c = \frac{\Gamma\left(\frac{\eta+1}{2}\right)}{\sqrt{\pi(\eta-2)}\Gamma\left(\frac{\eta}{2}\right)}.$$

## DCC

Tse & Tsui (2000) and R. Engle (2002) introduced the dynamic conditional correlations (DCC) as an extension to the CCC model of Bollerslev (1990), to correct for constant correlation over time. The variance-covariance matrix is defined as:

$$H_t = D_t R_t D_t, \quad (4)$$

where  $D_t = \text{diag} \sqrt{h_{i,j}}$ .  $D_t$  is a diagonal matrix containing the conditional standard deviations on the leading diagonal;  $R_t$  is the conditional correlation matrix, its specification is formulated by R. Engle (2002) as  $R_t = \text{diag} \{Q_t\}^{-1} Q_t \text{diag} \{Q_t\}^{-1}$ .  $Q$  comes from a general MGARCH model where more complex positive definite multivariate GARCH models could be used for the correlation parametrizations.

$$Q = S \circ (u' - A - B) + A \circ \varepsilon_{t-1} \varepsilon_{t-1}' + B \circ Q_{t-1}, \quad (5)$$

<sup>1</sup>We report information on returns rather than on exchange rates, as the former are covariance stationary while the latter don't. Returns are computed as the logarithmic difference of nominal exchange rates.

$$r_{i,t} = \ln(Y_{i,t}) - \ln(Y_{i,t-1}). \quad (1)$$

All exchange rates are computed as the number of units of each country's currency that buy one US dollar.

Table 1  
Exchange rates returns. Descriptive Statistics.

	AUD	HKD	INR	IDR	JPY	MYR	NZD	SGD	KRW	THB	TWD	PHP
Mean.	-3.15e-06	1.18e-08	-0.0001	-0.0002	2.07e-05	7.32e-05	3.34e-05	2.70e-05	-6.08e-05	-4.76e-05	-2.35e-05	-9.81e-05
Median.	0.0002	0.00	0.00	0.00	0.00	0.00	0.0001	0.00	0.00	0.00	0.00	0.00
Maximum.	0.0827	0.0062	0.0347	0.2309	0.0705	0.0985	0.0451	0.0371	0.2034	0.0855	0.0323	0.0644
Minimum.	-0.0729	-0.0028	-0.0610	-0.1999	-0.0547	-0.0770	-0.0673	-0.0302	-0.1525	-0.1779	-0.0333	-0.1085
Std.Dev.	0.0075	0.0003	0.0041	0.0135	0.0068	0.0050	0.0075	0.0035	0.0086	0.0059	0.0029	0.0061
Skewness.	-0.2555	0.9591	-1.2494	-0.7468	0.3594	0.4196	-0.2234	0.1825	-0.2602	-3.9070	-0.3543	-1.1868
Kurtosis.	12.543	29.377	24.502	84.303	8.5256	76.403	6.5774	12.061	104.41	154.53	18.458	39.589
Jarque-Bera.	25086.5	192121.2	128704.5	1816225.	8528.2	1480114.	3570.1	22588.7	2824798	6323502.	65777.1	369271.9
Probability.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Kolmogorov-Smirnov.	0.06	0.22	0.14	0.23	0.06	0.19	0.05	0.07	0.17	0.17	0.11	0.14
Probability.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 2  
Best fit ARIMA models.

Country	ARIMA	AIC	BIC
Australia	(1,1,1)	-49368.54	-49348.16
Hong Kong	(1,1,1)	-113245.4	-113225.1
India	(0,1,2) with drift	-102750.9	-102723.7
Indonesia	(1,2,1)	-64371.53	-64351.15
Japan	(0,1,0)	-108383.1	-108376.2
Malaysia	(4,1,4)	-67904.48	-67843.34
New Zealand	(0,1,0)	-51445.11	-51438.31
Singapore	(0,1,3)	-60926.94	-60899.77
South Korea	(0,1,0)	-77876.19	-77869.4
Thailand	(1,1,1)	-95429.72	-95409.34
Taiwan	(0,1,0)	-103372.6	-103365.8
The Philippines	(1,1,1) with drift	-94573.04	94545.87

lower half bellow the diagonal presents the level plots or contours and the half above indicates the Kendall's taus measure of all possible pairs. These uniform margins are used for analysing their joint distribution and ultimately their tail dependence structure.

#### 4. Sklar's theorem, 1959

Copula functions are useful for modelling multivariate dependence, especially when normality fails to be a good assumption for distributions, as in our case. Moreover, Copulas facilitate isolating dependence between random variables from their marginal distributions.

Since the probability integral transform is invertible, the copula also describes the dependence between the original variables. Notably in economics there is often more information about marginal distributions of related variables than their joint distribution. Inasmuch as copulas can capture dependence structure regardless of the form of the margins, a copula approach is likely very useful in econometrics.

where  $\circ$  is the Hadamard product;  $A, B$  and  $(u' - A - B)$  are positive semidefinite and  $Q$  will be positive semidefinite.

Chiang, Jeon, & Li (2007) implemented a symmetric DCC-GARCH to eight daily Asian stock-return data series from 1990-2003. The DCC-GARCH specification in this document accounts for asymmetric effects as recommended by Cappiello, Engle, & Sheppard (2006), i.e. volatility increases more after a negative shock than after a positive shock of the same magnitude. This model is appropriate for measuring time-varying conditional correlations and the responses to news and innovations. The standard residual for our model to each currency are displayed in figure 3.

The pseudo-sample associated with these residuals to uniform margins ( $u_1, u_2 \in [0, 1]$ ) can be use to construct currency-pairs as presented in figure 4. In this matrix the

Succinctly, let a  $n$ -dimensional distribution function  $H$  be decompose into two parts, the marginal distribution functions  $F_i$  and the copula  $C$ . Let  $H$  be a joint distribution function with margins  $F_i$ . Then there exists a copula  $C$  such that for all  $x_i$  in  $\bar{R}^n$  following the seminal work of Sklar (1959),

$$H(x_1, \dots, x_n) = C(F_1(x_1), \dots, F_n(x_n)). \quad (6)$$

Let  $F_1, \dots, F_n$  be the distribution functions. If  $F_1, \dots, F_n$  are all continuous, then  $C$  is unique; otherwise,  $C$  is uniquely determined on  $\text{Ran}F_1 \times \dots \times \text{Ran}F_n$ . Conversely, if  $C$  is a  $n$ -copula and  $F_1, \dots, F_n$  are distribution functions, then the function  $H$  defined above is a  $n$  distribution function with margins  $F_1, \dots, F_n$  (see Joe, 1997; Nelsen, 2007).

## R-vine

A flexible graphical method proposed by various authors Joe (1996); Bedford & Cooke (2001, 2002); Kurowicka & Cooke (2006) describes multivariate copulas as dependency model for the distribution of certain pairs of variables conditional on a specified set of variables. Using this cascade of bivariate copulas, so called *pair-copulas construction* (PCC); the recognition of the needed pairs of variables and their set of conditional variables is facilitated by an array of trees.

Vines arrange the  $n(n-1)/2$  pair-copulas of a  $n$ -dimensional PCC in  $n-1$  linked trees. In general, the structure captures conditional dependencies in higher trees and the order of the nodes are selected in such a way that the strongest pairwise dependencies are capture in the first tree.

The specification of the R-vine copula has the following arguments:  $(\mathbf{F}, \nu, \mathbf{B})$  is an R-vine copula specification if  $\mathbf{F} = (F_1, \dots, F_n)$  is a vector of continuous invertible distribution functions, as Sklar's Theorem illustrated in equation 6,  $\nu$  is an  $n$ -dimensional R-vine and  $\mathbf{B} = \{B_e | i = 1, \dots, n-1; e \in E_i\}$  is a set of copula with  $B_e$  being a bivariate copula  $(X_{C_{e,a}}, X_{C_{e,b}})$ .

The R-vine decomposition of a multivariate density is:

$$f(x_1, \dots, x_n) = \prod_{k=1}^n f_k(x_k) \times \prod_{i=1}^{n-1} \prod_{e \in E_i} c_{C_{e,a}, C_{e,b} | D_e} (F_{C_{e,a} | D_e}(x_{C_{e,a}} | x_{1D_e}, \dots, x_{nD_e}), F_{C_{e,b} | D_e}(x_{C_{e,b}} | x_{1D_e}, \dots, x_{nD_e})), \quad (7)$$

where  $f_k$  is the marginal densities  $k = 1, \dots, n$ ,  $c_{C_{e,a}, C_{e,b} | D_e}$  is the copula density of  $B_e$  for edge  $e = \{a, b\}$  and  $x_{iD_e} \in D_e$  for  $i = 1, \dots, n$ . Joe (1996) describes the strategy to obtain the conditional distributions  $F_{C_{e,a} | D_e}(x_{C_{e,a}} | \cdot)$  and  $F_{C_{e,b} | D_e}(x_{C_{e,b}} | \cdot)$ .

## Tail dependence

The concept of tail dependence is used as an advanced device to identify contagion among currencies when extreme values occur. This measure is only copula based and can thus be used in the parametrization of copulas. Joe (1997) defines this as the amount of dependence in the upper-quadrant tail or lower-quadrant tail of a bivariate distribution.

By definition:

$$\lambda_L = \lim_{u \searrow 0} \frac{C(u, u)}{u} \quad (8)$$

and

$$\lambda_U = \lim_{u \nearrow 1} \frac{1 - 2u + C(u, u)}{1 - u} \quad (9)$$

where  $\lambda_L$  is the lower tail and  $\lambda_U$  is the upper tail dependence for given bivariate copula family and parameter(s).

A copula is said to have a lower (upper) tail dependence if  $\lambda_L \neq 0$  ( $\lambda_U \neq 0$ ). The lower tail dependence measure ( $\lambda_L$ ) is the limiting value of  $\frac{C(u, u)}{u}$ , which is the conditional probability  $Pr[U_1 < u | U_2 < u] (= Pr[U_2 < u | U_1 < u])$  and the upper tail dependence ( $\lambda_U$ ) is the conditional probability  $Pr[U_1 > u | U_2 > u] (= Pr[U_2 > u | U_1 > u])$ .

## 5. Estimation

This document uses the automated strategy of jointly searching the appropriate R-vine tree structure, the pair copula families and their parameter values, formulated Dissmann, Brechmann, Czado, & Kurowicka (2013). Succintly, the method consists in selecting exchange rate pairs, finding the best bivariate copula families for each pair using information criteria, and estimating the corresponding parameters by Maximum Likelihood.

Table 4 presents estimation results. The first column displays the tree number. The edge, shown in the second column, presents pair-currencies (unconditional for the first tree while conditional for the rest of them). The best type of copula fit are presented in the third and fourth columns. The other three columns show information on the value of parameters and Kendall's Tau. Note that a t distribution is frequently the most adequate for the different exchange rate pairs. Other distributions that frequently appear as adequate belong to the SBB family.

The Malaysia ringgit maximizes the sum of the absolute empirical Kendall's Tau (see figure 4).

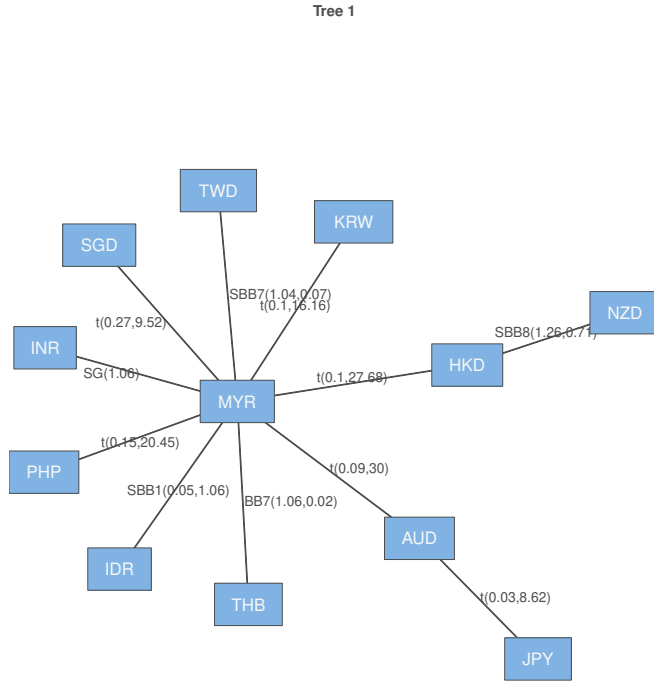
$$\max_{e=\{j,k\} \text{ in spanning tree } \widehat{\tau}_{jk}} \quad (10)$$

In other words, the first spanning tree (figure 1) presents Malaysia's ringgit as the main node while the rest of the currencies are its immediate edges (except for Japan's yen and New Zealand's dollar). These two currencies are connected to the network through other currencies. In the case of the Yen, its connection is mediated by the Australian Dollar. Meanwhile, New Zealand's Dollar is connected through Hong Kong's currency.

These are interesting results. They are useful for investors, as they highlight important issues regarding diversification opportunities. Specifically, we show that Malaysia is the main shock transmitter. However, volatility transmission flows first to most countries of the Asia-Pacific region, including Australia and Hong Kong, while Japan and New Zealand are only indirectly affected by their connection to

other countries in the network.

Figure 1. Tree 1 in R-vine.



Note: The estimates for the best copula fit are out side the parenthesis (and the parameters values are inside the brackets), on each branch.

Since we want to identify contagion among currencies when extreme values occur, the tails values are calculated using definitions 8 and 9. The upper tail dependence of the twelve Asian exchange rates are displayed on the top right panel of table 3. Upper tail dependence is associated with currencies co-movement for large depreciations. On the other hand, lower tail dependence indicates large appreciations as shown on the bottom panel in the same table.

Table 3 shows our main results regarding tail dependence. Notice that tail values are mainly symmetric and their probabilities are lower than 1% (however, different from zero in most cases). The fact that values are symmetric for most pairs implies that interdependence is similar in times of extreme currency appreciations and depreciations with respect to the US Dollar. This result, that contrasts with those of the majority of studies (see Loaiza-Maya, Gómez-González, & Melo-Velandia, 2015a,b), shows that phenomena such as the “fear of appreciation” (see Levy-

Yeyati, Sturzenegger, & Gluzmann, 2013) are not present in the Asia-Pacific region. In other words, while central banks in these countries conduct exchange rate intervention, it appears that their interventions do not depend on whether the exchange rate is devaluating or revaluating. In this sense, the “fear of appreciation” seems to be a common phenomenon mostly in Latin American and East European economies.

Pair-currencies with both tails equal to zero. ( $\lambda_L = 0$  and  $\lambda_U = 0$ ) as in Gaussian copulas are: Australian dollar-(Indian rupee, Indonesian rupiah, Malaysia ringgit, Thailand baht), Hong Kong dollar-(Indian rupee, Malaysia ringgit, New Zealand dollar), Indian rupee-(New Zealand dollar, Singapore dollar, Taiwan new dollar), Indonesia rupiah-(Japan yen, Taiwan new dollar, Philippine peso), Japan yen-(Malaysia ringgit, Singapore dollar, Thailand baht, Taiwan new dollar) and Malaysia ringgit-(New Zealand dollar, Singapore dollar, South Korea won). In other words for these cases there is not contagion from large appreciations or depreciations.

This finding then encourages the same results as Forbes & Rigobon (2001); Basu (2002); Bordo & Murshid (2000). In other words, transmission mechanisms are fairly stable among this currencies and that little contagion can be spread. One interpretation is that the Asian financial crisis of 1997-1998 made necessary to implement various types of policy coordination which main purpose was to internalize the externalities and spill-over effects that arise from economic regionalism. Moreover, there was a growing resentment toward the International Monetary Fund (IMF) and U.S. handling of the crisis that intensified the interest in the East Asian Economic Group (EAEG), which took the form of the ASEAN Plus Three (APT) framework.

Central banks and governments in East Asia agreed to create a regional self-help mechanism for effective prevention and management of financial crises which included regional economic surveillance led by the Economic Review and Policy Dialogue (ERPD), a regional liquidity support facility, called the Chiang Mai Initiative (CMI), and local-currency bond market development. Kawai (2005) suggests that the lesson from the Asian financial crisis was a clear need for effective prevention, management and resolution of financial crises and contagion. A thought that seems to justify the tail dependence values in upper and lower cases equal to zero.

The Philippine peso-Taiwan new dollar have only a lower tail or appreciation probability greater than 5%. The ASEAN currencies Philippine peso-Thailand baht have symmetric upper and lower tails greater than 1%.

Table 3  
Tail Dependence.

	AUD	HKD	INR	IDR	JPY	MYR	NZD	SGD	KRW	THB	TWD	PHP
AUD		2.70e-10	0.00	0.00	2.15e-3	0.00	5.14e-6	1.01e-2	4.77e-6	0.00	2.69e-4	1.35e-2
HKD	0.00		0.00	3.67e-6	9.32e-5	0.00	0.00	0.00	1.73e-2	6.63e-4	1.56e-3	7.29e-2
INR	0.00	0.00		9.18e-6	0.00	1.27e-4	0.00	0.00	6.39e-6	3.75e-5	0.00	6.40e-4
IDR	0.00	3.67e-6	9.18e-6		0.00	3.54e-6	3.65e-6	4.93e-5	0.00	1.40e-3	0.00	0.00
JPY	2.15e-3	9.32e-5	4.19e-2	0.00		0.00	8.08e-6	0.00	1.97e-3	0.00	0.00	1.77e-5
MYR	0.00	0.00	1.27e-4	3.54e-6	0.00		0.00	0.00	0.00	2.57e-5	6.91e-8	0.00
NZD	5.14e-6	0.00	0.00	3.65e-6	8.08e-6	0.00		1.12e-2	1.35e-5	0.00	3.88e-2	4.25e-5
SGD	1.01e-2	1.16e-2	0.00	4.93e-5	0.00	0.00	0.00		5.60e-6	7.09e-4	1.16e-4	6.07e-7
KRW	4.77e-6	0.00	6.39e-6	2.91e-14	1.97e-3	0.00	1.35e-5	5.60e-6		0.0075	0.0003	0.0015
THB	0.00	6.63e-4	3.75e-5	1.40e-3	0.00	2.57e-5	1.88e-2	7.09e-4	0.0075		0.0011	0.0321***
TWD	2.69e-4	1.56e-3	0.00	0.00	0.00	0.00	5.34e-7	1.16e-4	0.0003	0.0011		5.92e-5
PHP	1.35e-2	3.33e-14	6.40e-4	0.00	1.77e-5	7.77e-2	4.25e-5	7.52e-2	0.0015	0.0321***	0.0507**	

\*\*\*if  $\lambda_L$  or  $\lambda_U \geq \Pr[1\%]$ ; \*\*if  $\lambda_L$  or  $\lambda_U \geq \Pr[5\%]$ .

## 6. Conclusions

This paper studies Exchange rate contagion in the Asia-Pacific region. Using daily data spanning the period November 1991 to March 2017, together with DCC-GARCH models and copula functions, the paper explores the behavior of interdependence in times of extreme market appreciations and depreciations and their potential asymmetric effects.

In this context, contagion is considered as a situation in which exchange rate cross-market linkages significantly increase after the occurrence of a shock in a country's financial market. The sample contains countries from a unique region as evidence shows that currency crises tend to be regional, i.e., they affect countries in geographical proximity.

The R-vine copula approach followed in this study allows the identification of the best bivariate copula family for each exchange rate pair, as permits the estimation of tail dependence coefficients for extreme exchange rate appreciations and depreciations. Results show that, in most cases, a t-copula or a copula pertaining to the SBB family are the best fit. Network centrality of Malaysia ringgit is identified, while the Japan yen and the New Zealand dollar are the most isolated currencies from the sample. These results provide important information for investors interested in portfolio balancing with assets from countries of the Asia-Pacific region.

Contrasting with other studies on contagion that follow a similar approach, results of this study indicate that important asymmetries are not encountered, and evidence of contagion is scarce. This result, which goes in line with those of Forbes & Rigobon (2001), suggests that exchange rate comovements in the region's currencies are due to high inter-

dependence between countries.

## References

- Arouri, M. E. H., Bellalah, M., Hamida, N. B., & Nguyen, D. K. (2012). Relevance of fair value accounting for financial instruments: some french evidence. *International journal of business*, 17(2), 209.
- Basu, M. R. (2002). *Financial contagion and investor" learning": An empirical investigation* (No. 2-218). International Monetary Fund.
- Bedford, T., & Cooke, R. M. (2001). Probability density decomposition for conditionally dependent random variables modeled by vines. *Annals of Mathematics and Artificial intelligence*, 32(1), 245–268.
- Bedford, T., & Cooke, R. M. (2002). Vines: A new graphical model for dependent random variables. *Annals of Statistics*, 1031–1068.
- Beirne, J., & Gieck, J. (2014). Interdependence and contagion in global asset markets. *Review of International Economics*, 22(4), 639–659.
- Bollerslev, T. (1990). Modelling the coherence in short-run nominal exchange rates: a multivariate generalized arch model. *The review of economics and statistics*, 498–505.
- Bordo, M. D., & Murshid, A. P. (2000). *Are financial crises becoming increasingly more contagious? what is the historical evidence on contagion?* (Tech. Rep.). National Bureau of Economic Research.
- Cappiello, L., Engle, R. F., & Sheppard, K. (2006). Asymmetric dynamics in the correlations of global equity and bond returns. *Journal of Financial econometrics*, 4(4), 537–572.
- Cherubini, U., Luciano, E., & Vecchiato, W. (2004). *Copula methods in finance*. John Wiley & Sons.

- Chiang, T. C., Jeon, B. N., & Li, H. (2007). Dynamic correlation analysis of financial contagion: Evidence from asian markets. *Journal of International Money and finance*, 26(7), 1206–1228.
- Claessens, S., & Forbes, K. (2001). International financial contagion: An overview of the issues and the book. In *International financial contagion* (pp. 3–17). Springer.
- Czado, C., Schepsmeier, U., & Min, A. (2012). Maximum likelihood estimation of mixed c-vines with application to exchange rates. *Statistical Modelling*, 12(3), 229–255.
- De Gregorio, J., & Valdes, R. O. (2001). Crisis transmission: Evidence from the debt, tequila, and asian flu crises. In *International financial contagion* (pp. 99–127). Springer.
- Dissmann, J., Brechmann, E. C., Czado, C., & Kurowicka, D. (2013). Selecting and estimating regular vine copulae and application to financial returns. *Computational Statistics & Data Analysis*, 59, 52–69.
- Dungey, M., Fry, R., González-Hermosillo, B., & Martin, V. (2006). Contagion in international bond markets during the russian and the Itcm crises. *Journal of Financial Stability*, 2(1), 1–27.
- Engle, R. (2002). Dynamic conditional correlation: A simple class of multivariate generalized autoregressive conditional heteroskedasticity models. *Journal of Business & Economic Statistics*, 20(3), 339–350.
- Engle, R. F., Gallo, G. M., & Velucchi, M. (2012). Volatility spillovers in east asian financial markets: a mem-based approach. *Review of Economics and Statistics*, 94(1), 222–223.
- Forbes, K., & Rigobon, R. (2001). Measuring contagion: conceptual and empirical issues. In *International financial contagion* (pp. 43–66). Springer.
- Glick, R., & Rose, A. K. (1999). Contagion and trade: Why are currency crises regional? *Journal of international Money and Finance*, 18(4), 603–617.
- Hansen, B. E. (1994). Autoregressive conditional density estimation. *International Economic Review*, 705–730.
- Joe, H. (1996). Families of m-variate distributions with given margins and m (m-1)/2 bivariate dependence parameters. *Lecture Notes-Monograph Series*, 120–141.
- Joe, H. (1997). *Multivariate models and multivariate dependence concepts*. CRC Press.
- Kawai, M. (2005). East asian economic regionalism: progress and challenges. *Journal of Asian Economics*, 16(1), 29–55.
- Kurowicka, D., & Cooke, R. M. (2006). *Uncertainty analysis with high dimensional dependence modelling*. John Wiley & Sons.
- Lee, S. B., & Kim, K. J. (1993). Does the october 1987 crash strengthen the co-movements among national stock markets? *Review of Financial Economics*, 3(1), 89.
- Levy-Yeyati, E., Sturzenegger, F., & Gluzmann, P. A. (2013). Fear of appreciation. *Journal of Development Economics*, 101, 233–247.
- Loaiza-Maya, R. A., Gómez-González, J. E., & Melo-Velandia, L. F. (2015a). Exchange rate contagion in latin america. *Research in International Business and Finance*, 34, 355–367.
- Loaiza-Maya, R. A., Gómez-González, J. E., & Melo-Velandia, L. F. (2015b). Latin american exchange rate dependencies: A regular vine copula approach. *Contemporary Economic Policy*, 33(3), 535–549.
- Lucey, B. M., & Voronkova, S. (2008). Russian equity market linkages before and after the 1998 crisis: Evidence from stochastic and regime-switching cointegration tests. *Journal of International Money and Finance*, 27(8), 1303–1324.
- Nelsen, R. B. (2007). *An introduction to copulas*. Springer Science & Business Media.
- Sklar, M. (1959). *Fonctions de répartition à n dimensions et leurs marges*. Université Paris 8.
- Tse, Y. K., & Tsui, A. K. (2000). A multivariate garch model with time-varying correlations.



Figure 2. Nominal exchange rates.

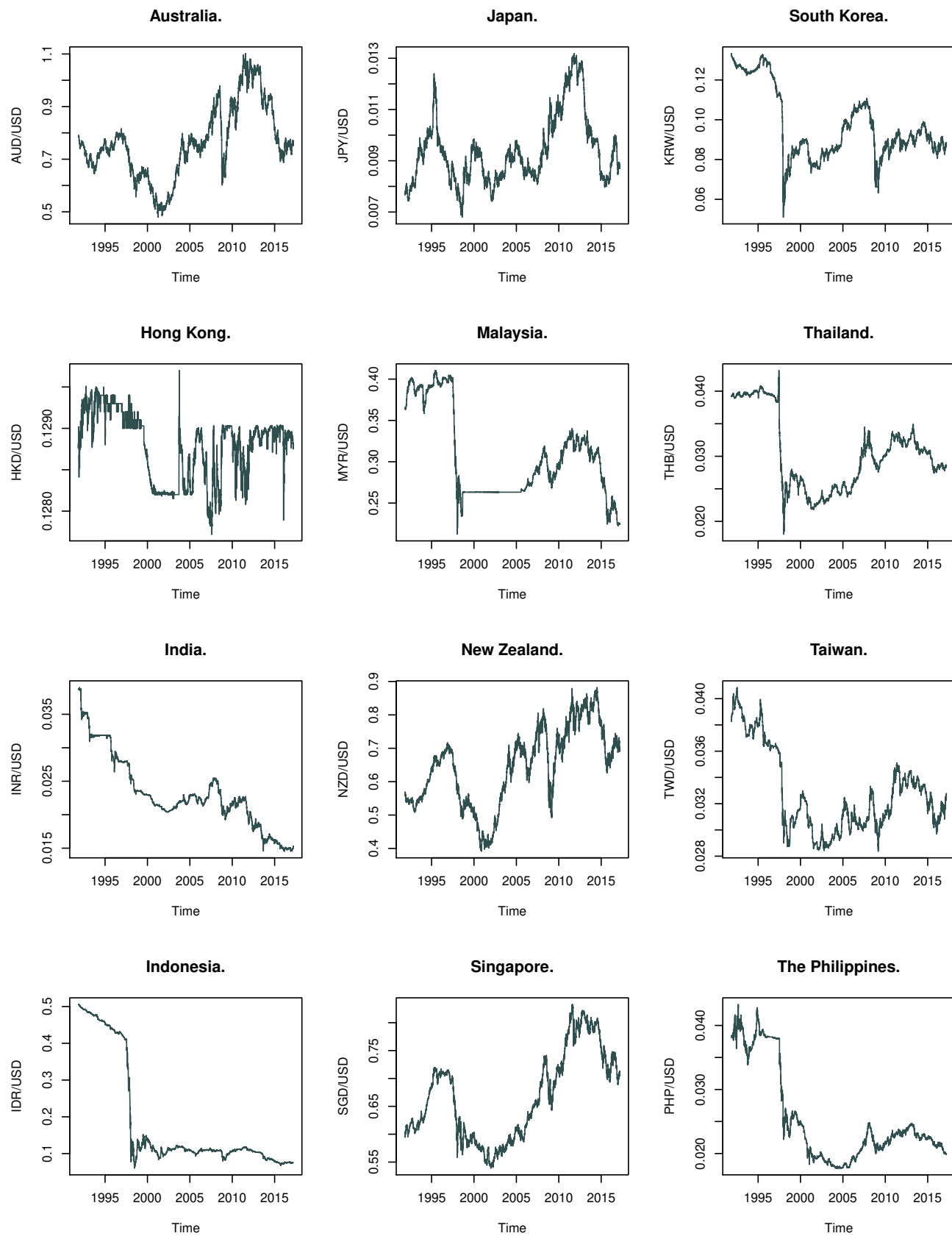
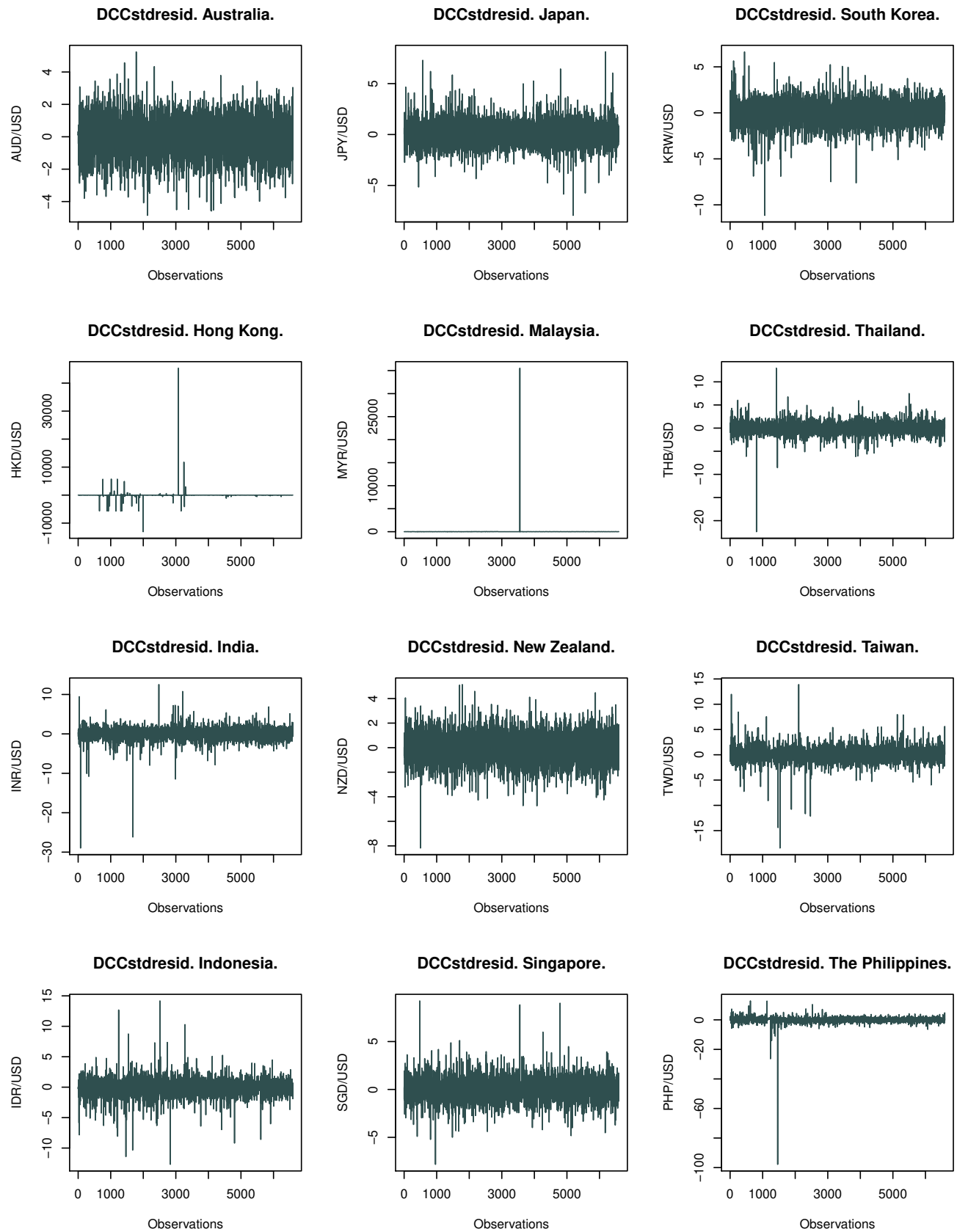


Figure 3. DCC standard residuals



	0.0 0.6		0.0 0.6		0.0 0.6		0.0 0.6		0.0 0.6		0.0 0.6	
AUD	0.037	0.012	0.013	0.022	0.062	0.022	0.014	0.0069	0.0057	0.01	0.0059	
HKD	0.029	0.013	0.012	0.063	0.043	0.052	0.0032	0.0023	0.0062	0.038		
INR	0.0037	0.0036	0.056	0.018	0.0038	0.007	0.017	0.0016	0.0014			
IDR	0.0063	0.079	0.013	0.017	0.0097	0.013	0.0011	0.012				
JPY	0.008	0.0018	0.015	0.0004	0.014	0.0075	0.00055					
MYR	0.031	0.17	0.062	0.035	0.045	0.096						
NZD	0.00068	0.0099	0.013	0.00016	0.012							
SGD	0.0014	0.015	0.016	0.032								
KRW	0.0055	0.014	0.026									
THB	0.0059	0.021										
TWD	0.012											
PHP												

Table 4

*R-vine.*

Tree <sup>†</sup>	Edge <sup>‡</sup>	No.	Family	Parameter	Parameter2	Tau
1	1,5	2	t	0.03	8.62	0.02
	6,10	9	BB7	1.06	0.02	0.04
	6,12	2	t	0.15	20.45	0.09
	2,7	20	SBB8	1.26	0.71	0.04
	6,1	2	t	0.09	30.00	0.06
	6,3	14	SG	1.06	0.00	0.06
	6,2	2	t	0.10	27.68	0.07
	6,4	17	SBB1	0.05	1.06	0.08
	6,9	2	t	0.10	16.16	0.06
	6,8	2	t	0.27	9.52	0.17
	11,6	19	SBB7	1.04	0.07	0.05
2	6,5 1	2	t	0.01	18.97	0.01
	8,10 6	2	t	-0.04	13.13	-0.02
	2,12 6	20	SBB8	1.15	0.76	0.03
	6,7 2	20	SBB8	1.06	0.96	0.03
	2,1 6	20	SBB8	1.12	0.87	0.03
	2,3 6	13	SC	0.04	0.00	0.02
	8,2 6	9	BB7	1.03	0.05	0.04
	8,4 6	2	t	-0.06	19.23	-0.04
	8,9 6	2	t	-0.03	17.47	-0.02
	11,8 6	2	t	-0.04	13.97	-0.02
3	2,5 6,1	5	F	-0.12	0.00	-0.01
	4,10 8,6	2	t	-0.03	15.45	-0.02
	3,12 2,6	2	t	-0.01	23.75	0.00
	1,7 6,2	2	t	0.02	14.65	0.01
	3,1 2,6	5	F	-0.15	0.00	-0.02
	8,3 2,6	2	t	-0.02	24.21	-0.01
	4,2 8,6	16	SJ	1.01	0.00	0.01
	9,4 8,6	2	t	-0.02	15.42	-0.02
	11,9 8,6	2	t	-0.02	9.38	-0.02
4	3,5 2,6,1	2	t	-0.00	29.59	-0.00
	2,10 4,8,6	6	J	1.01	0.00	0.01
	8,12 3,2,6	2	t	0.00	29.00	0.00
	3,7 1,6,2	3	C	0.02	0.00	0.01
	8,1 3,2,6	2	t	-0.01	13.06	-0.01
	4,3 8,2,6	33	C270	-0.02	0.00	-0.01
	9,2 4,8,6	2	t	0.00	26.75	0.00
	11,4 9,8,6	2	t	-0.01	28.76	-0.01
5	8,5 3,2,6,1	2	t	0.01	9.22	0.01
	3,10 2,4,8,6	14	SG	1.01	0.00	0.01
	1,12 8,3,2,6	0	I	-	-	0.00
	8,7 3,1,6,2	2	t	-0.02	22.70	-0.01
	4,1 8,3,2,6	5	F	-0.18	0.00	-0.02
	9,3 4,8,2,6	134	Tawn270	-1.07	0.06	-0.01
	11,2 9,4,8,6	4	G	1.01	0.00	0.01
6	4,5 8,3,2,6,1	2	t	0.01	30.00	0.01
	1,10 3,2,4,8,6	24	G90	-1.01	0.00	-0.01
	7,12 1,8,3,2,6	0	I	-	-	0.00
	4,7 8,3,1,6,2	2	t	-0.03	29.16	-0.02
	9,1 4,8,3,2,6	2	t	-0.02	27.56	-0.01
	11,3 9,4,8,2,6	33	C270	-0.02	0.00	-0.01
7	10,5 4,8,3,2,6,1	5	F	0.12	0.00	0.01
	7,10 1,3,2,4,8,6	5	F	-0.15	0.00	-0.02
	4,12 7,1,8,3,2,6	2	t	0.00	20.73	0.00
	9,7 4,8,3,1,6,2	2	t	-0.01	30.00	-0.01
	11,1 9,4,8,3,2,6	224	Tawn2	90	-1.05	0.10 -0.01
8	7,5 10,4,8,3,2,6,1	2	t	0.00	13.12	0.00
	12,10 7,1,3,2,4,8,6	2	t	0.02	22.28	0.02
	9,12 4,7,1,8,3,2,6	16	SJ	1.03	0.00	0.02
	11,7 9,4,8,3,1,6,2	0	I	-	-	0.00
9	12,5 7,10,4,8,3,2,6,1	0	I	-	-	0.00
	9,10 12,7,1,3,2,4,8,6	2	t	-0.01	30.00	-0.01
	11,12 9,4,7,1,8,3,2,6	2	t	0.01	28.18	0.01
10	9,5 12,7,10,4,8,3,2,6,1	0	I	-	-	0.00
	11,10 9,12,7,1,3,2,4,8,6	23	C90	-0.03	0.00	-0.01
11	11,5 9,12,7,10,4,8,3,2,6,1	13	SC	0.03	0.00	0.02

<sup>†</sup>LogLik= 1081.76, AIC= -1955.53, BIC= -1248.98<sup>‡</sup> 1: Australia, 2: Hong Kong, 3: India, 4: Indonesia, 5: Japan, 6: Malaysia, 7: New Zealand, 8: Singapore, 9: South Korea, 10: Thailand, 11: Taiwan, 12: The Philippines.